The SunShot Program

The Dollar a Watt Team

Imagine a World…

What if we had subsidy-free solar electricity at an LCOE of 5-6 ¢/kWh ???

- Scaling without Subsidies
- Jobs and Competitiveness
- National Energy Security
- Healthy Environment

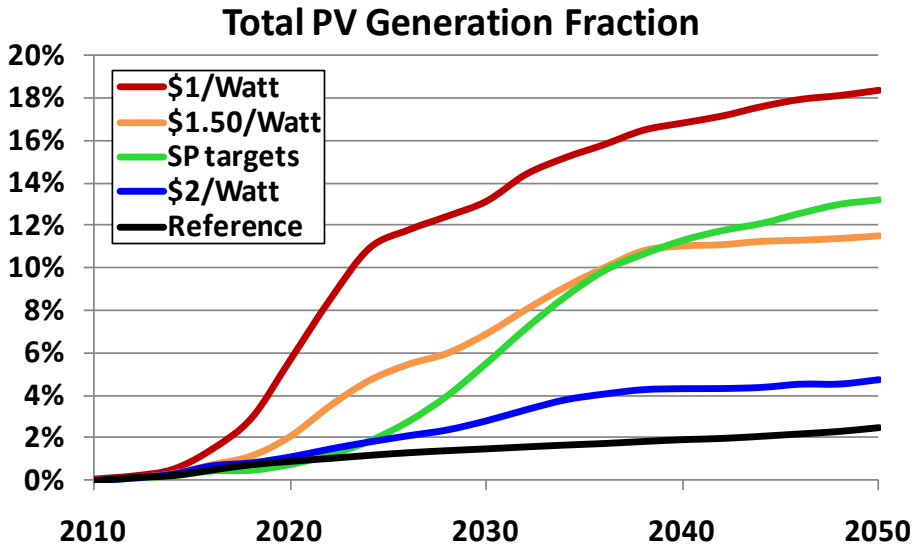
SunShot

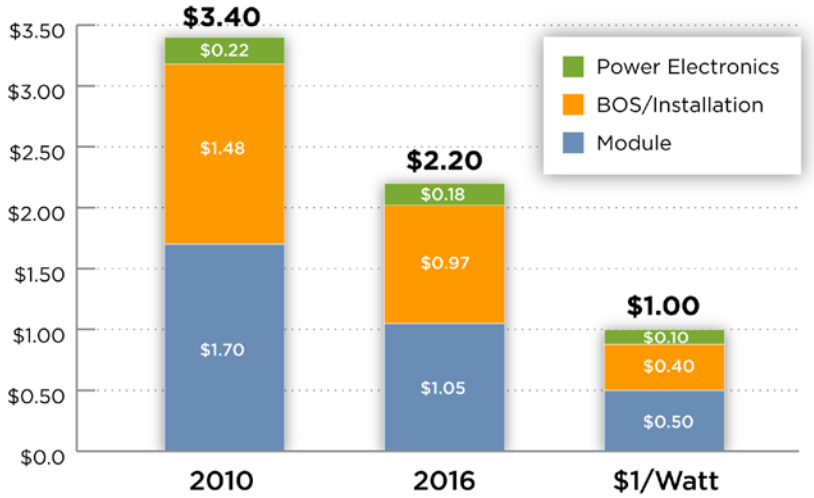
What is SunShot?

- **Price and date targets**
  - 5-6¢/kWh fully installed at the MW scale by 2020
  - Unsubsidized grid parity in residential and commercial markets by 2020

- **Transformational technologies**
  - PV Modules
  - BOS
  - Power Electronics

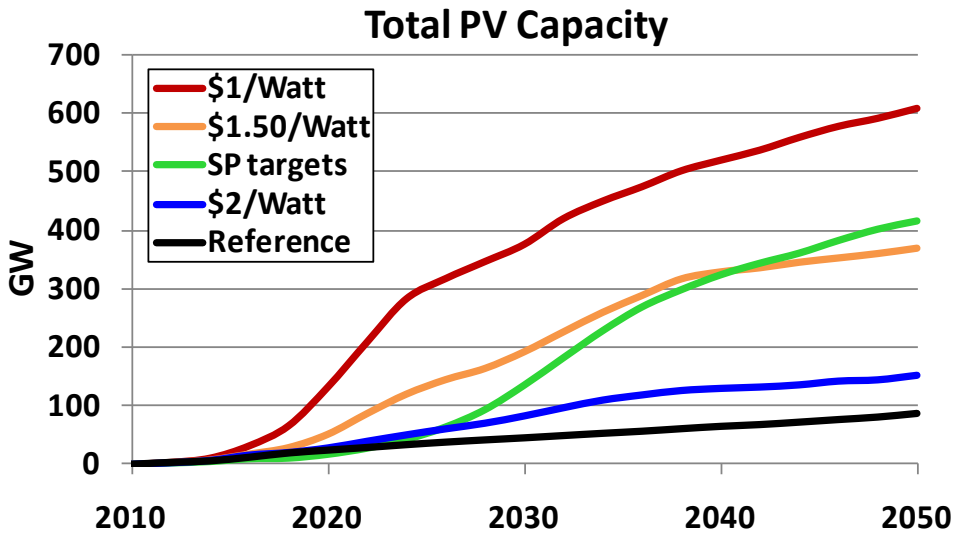
SunShot enables unsubsidized deployment of solar energy





Goodrich, Margolis, et al

NREL

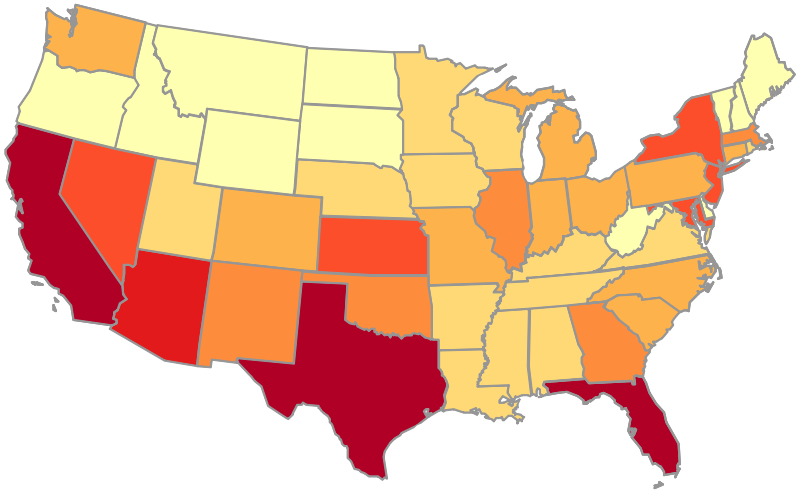


SunShot enables unsubsidized deployment of solar energy

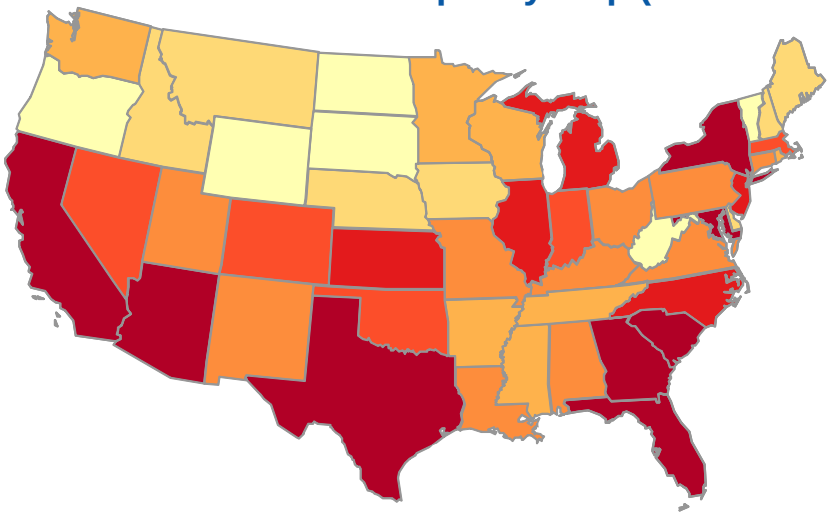
U.S. DEPARTMENT OF ENERGY

SunShot

$1/Watt 2030 Cumulative PV Capacity Map (375 GW total)



$1/Watt 2050 Cumulative PV Capacity Map (610 GW total)



Total PV Capacity (GW)
< 1
1 - 3
3 - 5
5 - 8
8 - 12
12 - 17
> 17

Goodrich

NREL

Taking a Team Approach

U.S. DEPARTMENT OF ENERGY
SunShot

R. Ramesh
SunShot Director

Minh Le
PV Module
EERE

Module Task Force (EERE)
GOAL : 50c /Watt

Power Electronics (ARPA-E) GOAL 10c /Watt

Rajeev Ram
Power Electronics
ARPA-E

Tex Wilkins
CSP
EERE

Fundamental Research (SC)

Balance of Systems (EERE) GOAL: 40c /Watt

Kevin Lynn
Systems Integration
EERE

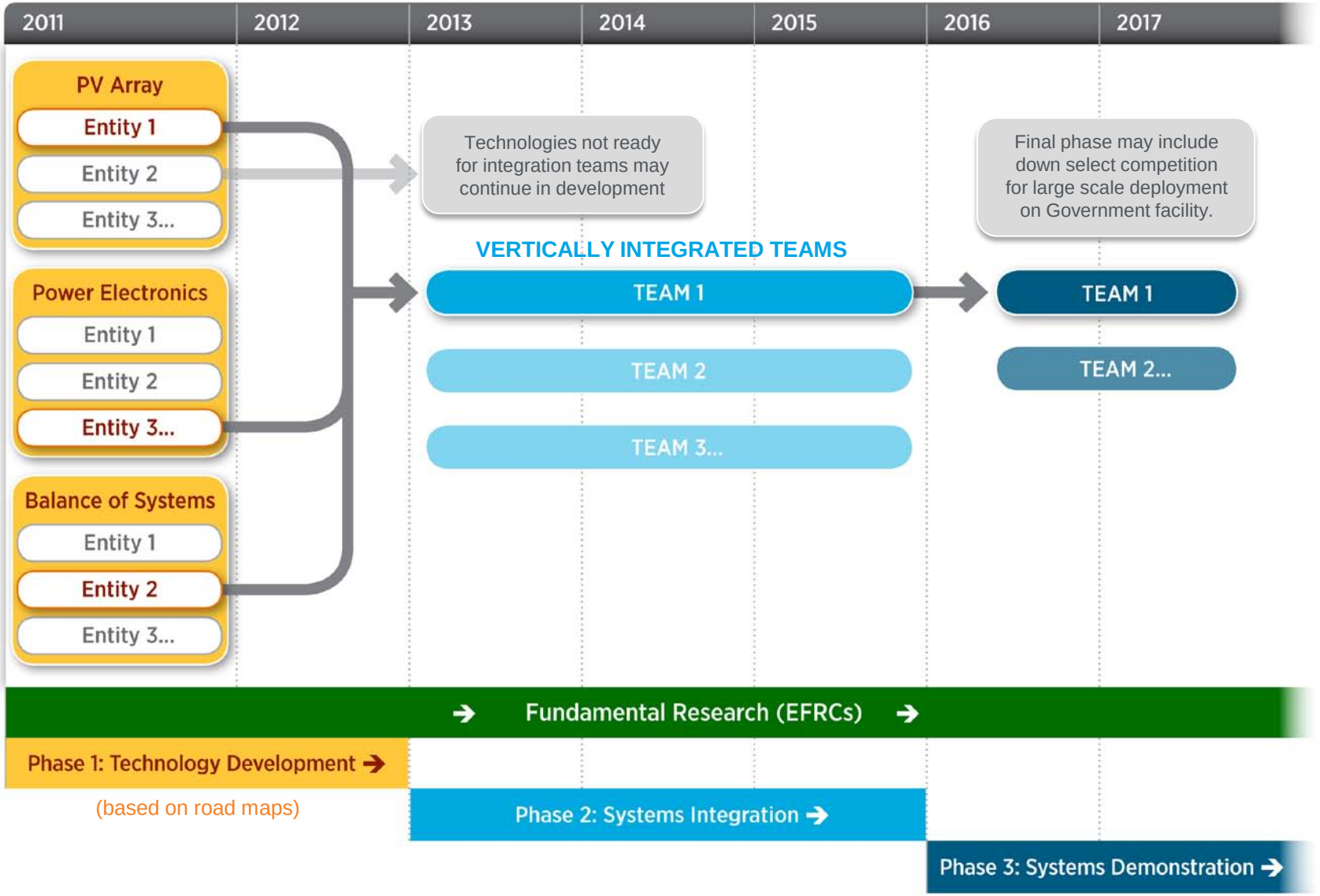
Jim Horwitz
Fundamental Science
OS

Jennifer De Cesaro
BOS-Software
EERE

Rachel Tronstein &
John Lushetsky,
SunShot Strategic Planning, EERE

Advisory Board : Bill Brinkman (OS); Arun Majumdar (ARPA-E); Cathy Zoi (EERE)

Core Funding Strategy



R,D & D Roadmaps : Guiding Technology Development and Deployment

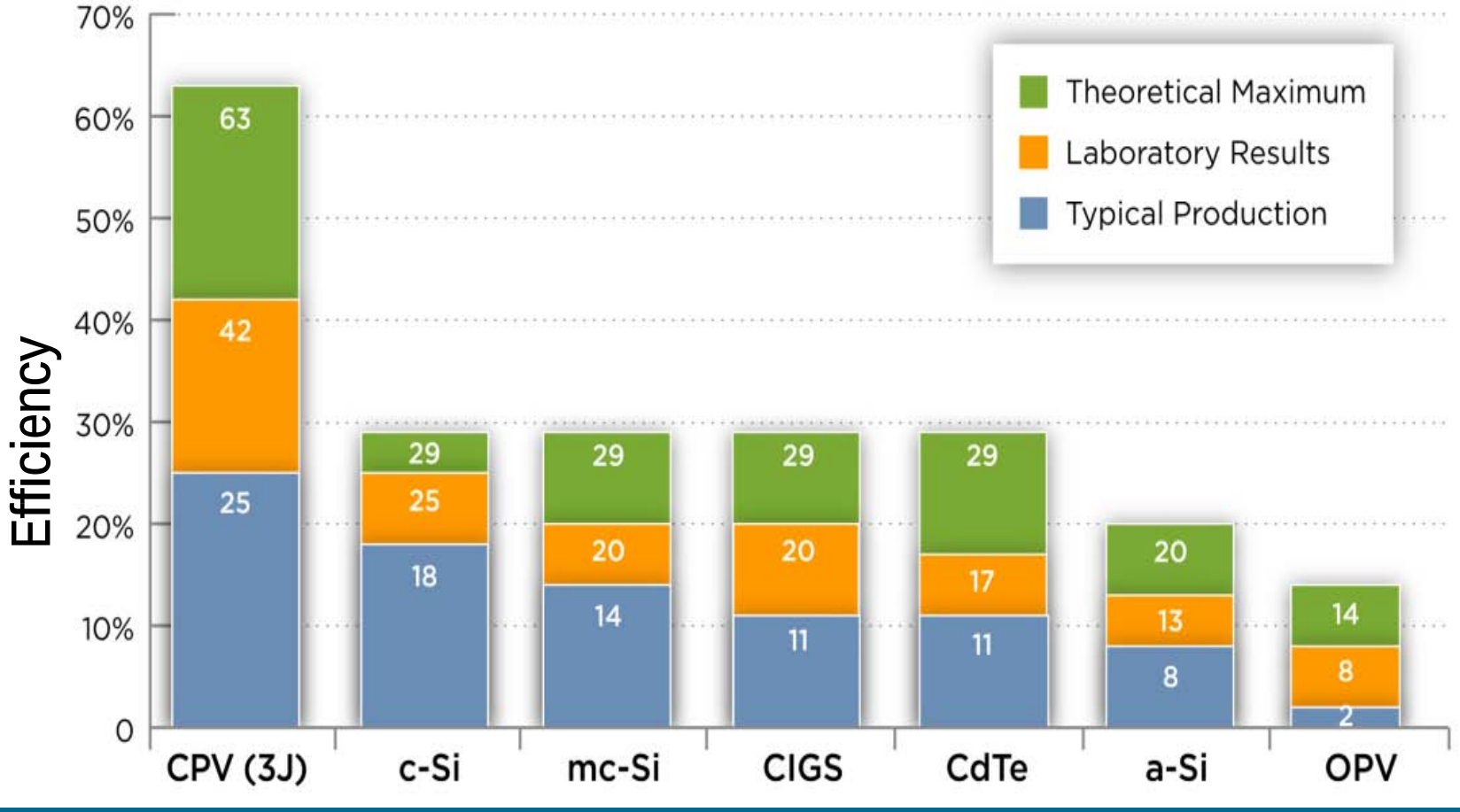
- Roadmap for **Module**: Materials, manufacturing, integration, reliability testing
- Roadmap for **Power Electronics**: Component innovations, communication protocols
- Roadmap for **Balance of System**: Materials, Design, Automation
- Industry, National Labs and Academia deeply involved in creating and implementing road maps

Engaging the stakeholders

- Dollar a Watt Workshop, August 2010
- Solar Roundtable, Jan 13
- Soft BOS workshop Feb 9
- Power Electronics Workshop Feb 8
- Hard BOS workshop Feb 9
- Manufacturing/Demonstration workshop March
- CSP workshop : March 2
- This workshop
- Website, blogsite,…
- More to come …

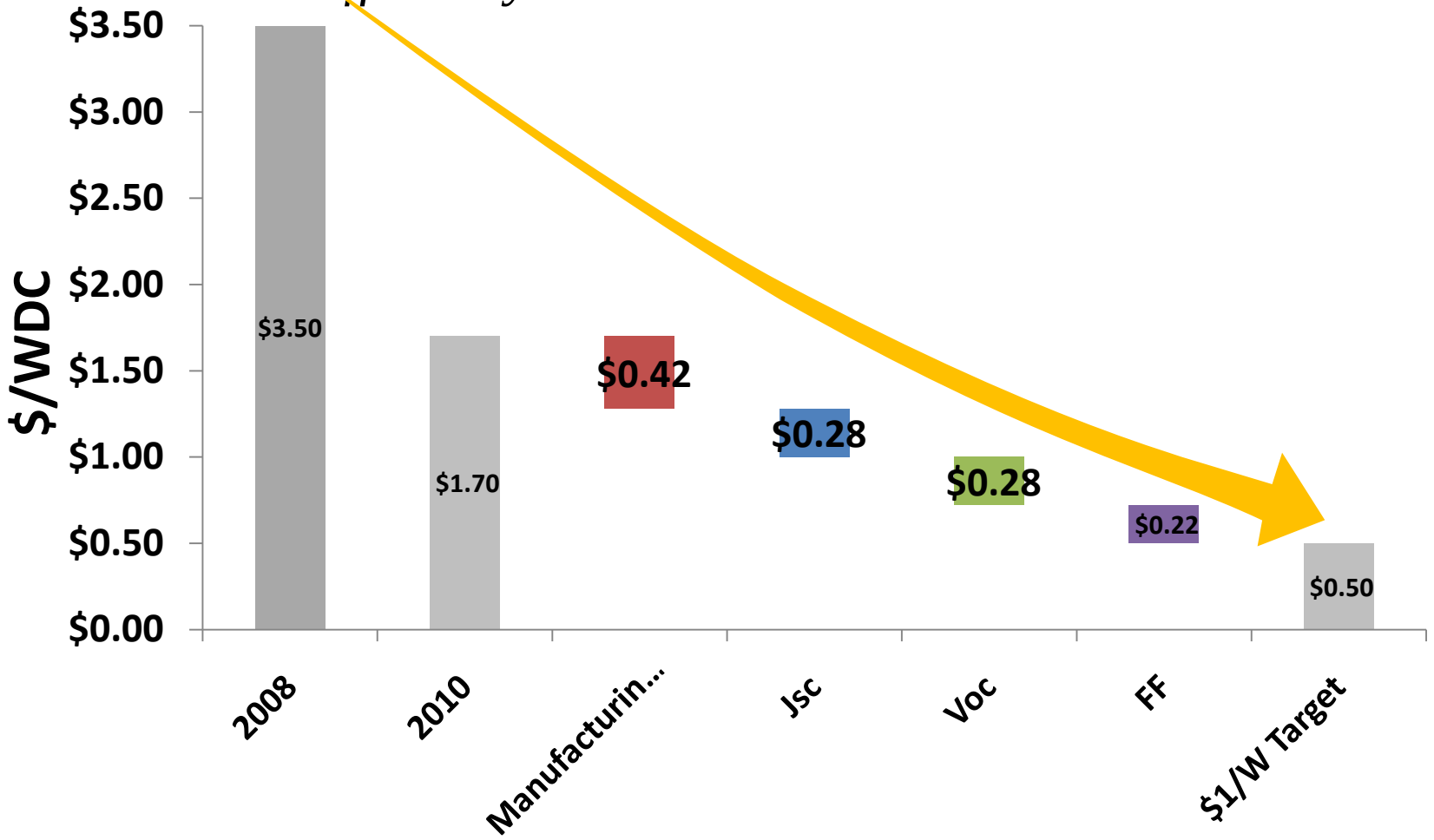
Algorithms : PV Module Technologies

$$\frac{\$}{Watt} \propto \frac{Manufacturing\ Cost}{Efficiency} \rightarrow \eta \propto J_{SC} \cdot V_{OC} \cdot FF$$



Barriers based investment : CIGS Modules

$$\frac{\$}{Watt} \propto \frac{Manufacturing\ Cost}{Efficiency} \rightarrow \eta \propto J_{SC} \cdot V_{OC} \cdot FF$$



Approach to 50c/W Modules: CIGS Modules

$$\frac{\$}{Watt} \propto \frac{Manufacturing\ Cost}{Efficiency} \rightarrow \eta \propto J_{SC} \cdot V_{OC} \cdot FF$$

Drivers	Cost Reduction Potential	Technical Risk	Pathways
Materials cost and availability (Indium, selenium, cadmium)	High	Medium	**Thinner** layers or replacement with **Earth abundant** and benign materials (e.g., CZTS, ZnS, …)
Transparent Conductors	High	Low	ITO alternative materials and/or deposition methodologies
Large scale spatial uniformity and improved throughput with same or lower cost of capital	High	Medium	Improved **in-situ metrology**, thermal control, and elimination of chemical bath CdS
Glass and/or Encapsulants	Medium	Medium	**Flexible** low-cost front and backsheets with low WVTR (i.e., ultrabarriers, glass replacement)
Operational costs of selenization ovens	Medium	Medium	Eliminate batch selenization, alternative **deposition methodologies** (e.g., atmospheric deposition).

Barriers based investments: CIGS Modules

$$\frac{\$}{Watt} \propto \frac{Manufacturing\ Cost}{Efficiency} \rightarrow \eta \propto J_{SC} \cdot V_{OC} \cdot FF$$

Action	Potential Current Increase (mA/cm^2)	Technical Risk	Pathways
Larger band gap junction partner	2.5	Medium	Replace CdS (e.g. 2.5 eV) with wide bandgap emitter (i.e., ZnS (3.1 eV))
Improved TCO	1.5	Medium	Develop TCO with high conductivity, transparency, environmental stability (i.e., **a-InZnO**)
Reduce CdS window layer thickness	1.5	Medium	Develop **20 nm thick** continuous CdS layer without shunting.
Minimize reflection off CIGS surface	1.5	Medium	Develop a suitable low cost **anti-reflection coating**
Improved monolithic integration	1	Low	Reduce line width of laser/mechanical scribing

Barriers based investments: CIGS Modules

$$\frac{\$}{Watt} \propto \frac{Manufacturing\ Cost}{Efficiency} \rightarrow \eta \propto J_{SC} \cdot V_{OC} \cdot FF$$

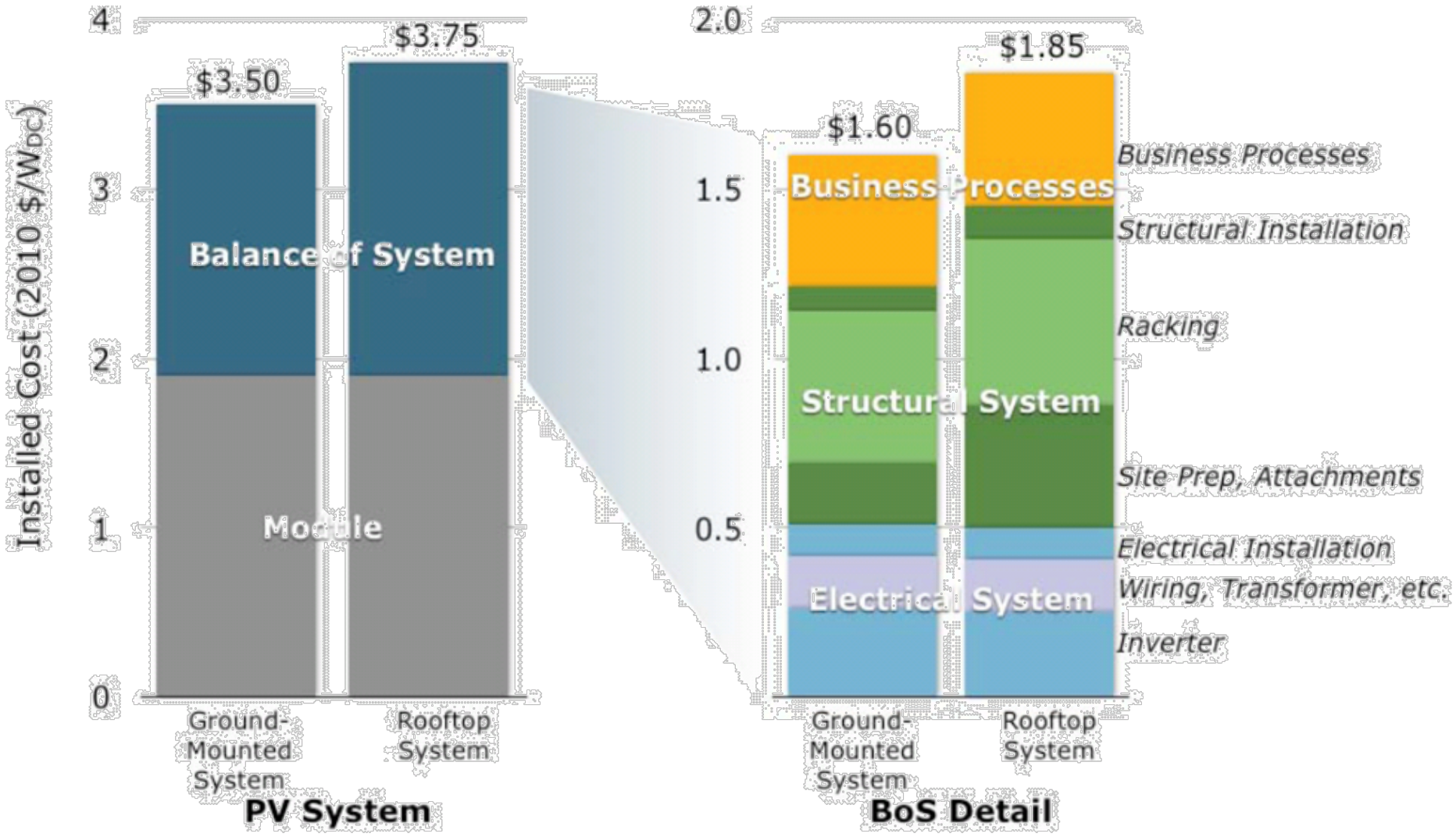
Action	Potential Voltage Increase (V)	Technical Risk	Pathways
Increase the Ga/In ratio in CIGS by a factor of 2 to 3	0.1	Medium	Increase CIGS deposition temperature via **higher temperature glass** substrates or alternative stable substrates.
Improve the absorber carrier lifetime and concentration	0.05	Medium	Implement **in-situ quality control** at minimal additional cost

Barriers based investments: CIGS Modules

$$\frac{\$}{Watt} \propto \frac{Manufacturing\ Cost}{Efficiency} \rightarrow \eta \propto J_{SC} \cdot V_{OC} \cdot FF$$

Action	Potential FF Increase	Technical Risk	Pathways
Reduce parasitic leakage current	0.10	Low	Improve the density, phase, and crystallinity of the absorber
Reduce contact resistance	0.07	Low	Improved TCO and contact grid combination

Balance of System



Power Electronics for Commercial Rooftop Solar

Goal: Module level MPPT (>98%)

Barrier: Cost & reliability

Approach: DC/DC or DC/AC module integrated converters

Goal: Light weight, roof-top inverter
99%, 200-500kW, eliminates DC conduit and wiring

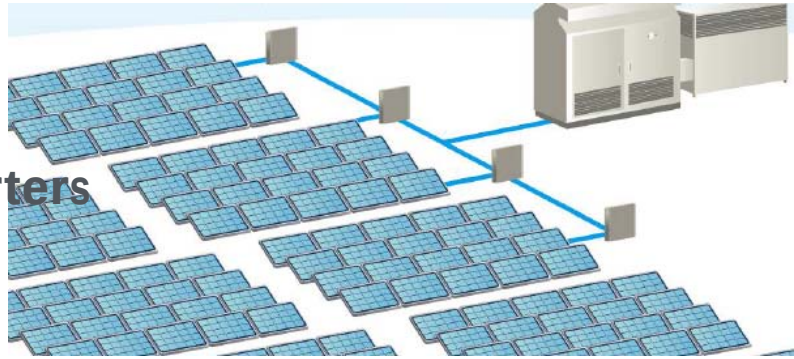
Barrier: High-frequency switches and magnetics
AC switches (for current drive architectures)

Approach: Wide-bandgap switches with advanced magnetic materials

Actively Engaging the Stakeholders:

Extracts from Power Electronics Workshop

Power Electronics for Utility Scale Solar



Goal: Consolidate the number of inverters
e.g., 20 MW installation will have 20 x 1MW inverters

Barrier: Longer wiring, limited by loss

Approach: Higher DC bus voltages
DC/DC boost converters at module string (w/ MPPT)

Goal: Improve power quality while delivering cost
high frequency electronics - improved EMI, reduced harmonics

Barrier: - Low loss, high-voltage switches and magnetics
- Utility 'ownership' of line frequency transformer

Approach: Wide-bandgap switches with advanced magnetic materials

Actively Engaging the Stakeholders:

Extracts from Power Electronics Workshop

Balance of Systems : A complex beast to tackle!!

	Today	2014	2017
BOS/Installation	$ 1.48	$ 0.97	$ 0.40
Mounting and Racking Hardware	$ 0.25		
Wiring	$ 0.14		
Other	$ 0.17		
Permits	$ 0.01		
System Design, Management, Marketing	$ 0.15		
Installer Overhead and Other	$ 0.19		
Installation Labor	$ 0.38		

BOS is different for Utility vs. Commercial vs. Residential

Utility Scale BOS

- Opportunity for small improvements in a range of areas

- Three elements of the strategy:
  1. **Design innovations**
  2. **Materials and Mechanics**
  3. **Installation approaches and automation**

Automation

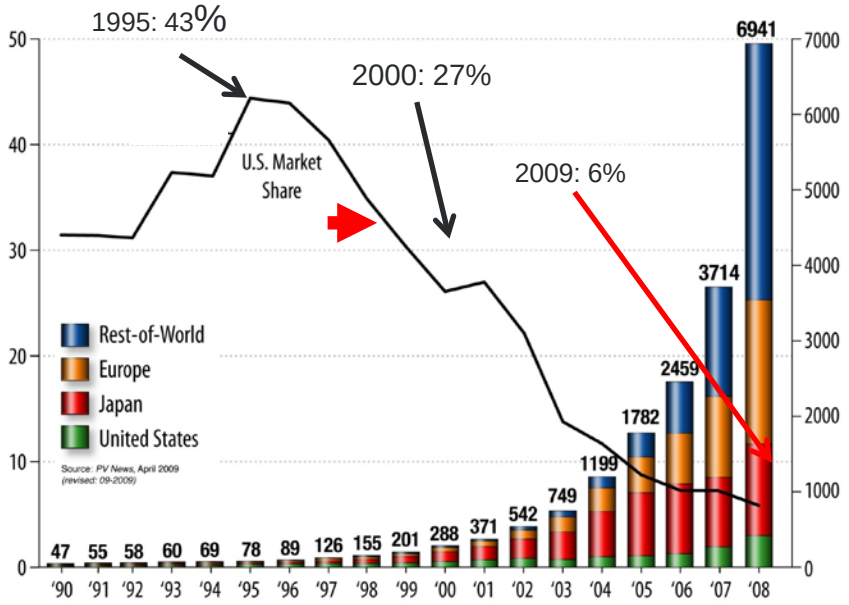
Plug and Play with BIPV

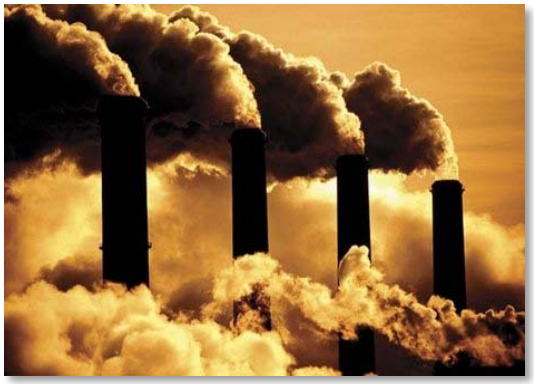
Wiring, Frameworks, Mechanics

- **Topic 1: Transformational Building Integrated Photovoltaic (BIPV) Modules (Cost Target <$2/W)**
  - Develop a business case for integrating PV into a roofing product with the potential for GW's of installations
  - Develop a partnership with a roofing company
  - Encourage the Integration of Power Electronics
  - Demonstrate a form factor and installation design that reduces the temperature of both the PV cell and the roof assembly
  - Develop a highly reliability product with lifetimes of 20 years or more
  - Demonstrate a form factor that can be quickly and easily installed.

Why SunShot ?

- **Global Competitiveness**
  - **Energy Security**
  - **Environmental Issues**
  - **Life without subsidies**





Thank You

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